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Effects of Female Facial Dimensions on Full Face Respirator Fit

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Abstract

Several types of respiratory protective equipment (RPE) were tested for inward leakage, whilst being worn by female test subjects. The inward leakage results were used to assess the goodness of fit of the RPE for each wearer. The results indicate that between ten and twenty percent of female wearers of RPE may not achieve an acceptable fit. The facial dimensions of the test subjects were used to generate an indicator of three dimensional size referred to as the composite face size. This proved to be a good indicator of RPE fit in most cases.

Introduction

Respiratory protective equipment (RPE) is increasingly being used by female wearers, and yet the reality is that much of the RPE currently available, has been designed for male users and has been tested on male test subjects.

The UK Health and Safety Executive (HSE) is concerned that females may not be achieving adequate protection from RPE. This work seeks to establish whether females can obtain protection from a selection of RPE, or whether there is a range of

small facial sizes which cannot obtain protection. The selection of RPE is such as might be offered within a single organisation.

All the RPE tested complied with the relevant European Standards and was in good condition. The study does not seek to challenge the conformity of the RPE with the Standard, or to compare them with each other: it seeks to assess the facial fit achieved by female wearers, of different facial sizes, when wearing the RPE.

RPE

Four items of RPE were selected from a much larger range of RPE on the UK market. One criterion used in choosing the RPE was that they collectively

they should offer a range of sizes, from a small face mask to a large face mask.

One hood and three full face masks were included in the study. Two full face masks had integral fans and filters, with belt mounted batteries. One full face mask had a belt mounted fan, battery and filter;

and was available in two sizes of face mask. These are anonymised in this report as Hood W, and face masks X, Y, Zm/l (medium/large) and Zm/s (medium/small).

Testing

The RPE was tested using thirteen female volunteers as test subjects, covering a wide range of facial sizes. Four facial dimensions are specified in European Standard (EN136) to describe RPE test subjects. The facial dimensions for test subjects in this study are shown in Table 1.

The test adopted in this study was the inward leakage(IL) test specified in European standards (EN136, EN146, and EN147). Tests consisted of the test subject wearing the RPE whilst walking on a treadmill at speeds up to 6km/hr. Whilst walking the test subjects carried out a series of head exercises:

- a) two minutes with the head still
- b) two minutes with the head moving slowly from side to side
- c) two minutes with the head moving slowly up and down.
- d) two minutes talking
- e) two minutes with the head still.

This provides a variety of movements and breathing patterns which should reveal a poor fit.

The RPE was used unpowered in order to maximise any leakage. Recent unpublished research has shown that increased inward leakage associated with poor facial fit is observed when the RPE is unpowered (Bailey *et al.*, 1998). However, the hood and one of the masks were unsuitable for unpowered use and these were tested at the manufacturer's minimum flow rate.

Testing was carried out in a chamber with an atmosphere containing approximately 1000 ppm of SF₆ gas. The RPE was fed with a supply of clean air via a flexible hose. By monitoring the air inside and outside the mask for SF₆ the face seal leakage throughout the test could be calculated.

Table 1. Facial dimensions of test subjects.

Test subject	Length of face (mm)	Width of face (mm)	Depth of face (mm)	Width of mouth (mm)	Composite face size (mm)
A	115	138	111	47	363.00
B	103	130	110.00	46	343.00
C	98	145	109	49.00	352.00
D	120.00	146	121	52	387.00
E	108	132.00	106	44	346.00
F	110	136	120	53	366.00
G	112	140	117	53	369.00
H	100	129	110	52	339.00
J	117	139	110.00	49	366.00
K	110.00	123.00	106.00	47.00	339.00
L	102.00	137.00	100.00	54.00	339.00
M	107.00	136.00	121.00	45.00	364.00
N	119.00	138.00	125.00	53.00	382.00

Composite face size = length of face + width of face + depth of face.

Results

Each test subject provided five IL results each time they tested RPE; one average result for each head exercise. The criterion adopted was that if there were visible gaps at the face seal or, any of the five results rose above 0.05% IL (the level adopted in

EN136) the RPE was judged to have failed to fit the test subject. The inward leakage (expressed as a percentage) for each device and subject is shown in Tables 2 to 5. Each test is classified as a pass or fail.

Discussion

This work has raised a number of issues related to both the testing and usage of RPE by female users.

Only five tests were carried out using the hood. As expected the hood performed well with female subjects with no observed characteristics of use peculiar to female users.

In the case of the three types of face mask the female users encountered a number of problems. These include examples of high face seal leakage and also problems in conducting the inward leakage tests according to European Standards. Experience in fit testing males, with the same selection of RPE, as shown that these problems are not normally seen with male wearers.

Figure 1 shows the subjects' length of face (LOF) and width of face (WOF) plotted on the Los Alamos grid (Hack and McConville, 1978). As expected female test subjects are mostly representative of the medium and small face.

We have observed in this and other work that no one facial dimension is a reliable indicator of fit. Thus a subject with a long face is equally likely to achieve a good fit as one with a short face. This is probably due to the flexibility of the masks. A 'composite face size' figure can be produced by adding the length of face, width of face, and depth of face, and we propose this as an attempt to develop a three dimensional indicator based on the dimensions already specified in European Standards. The tests are shown, in Fig. 2, as pass or fail against this composite face size, for each mask.

Difficulties have been experienced in performing inward leakage tests as specified in European Standards. The Standards specify the use of a 20 mm diameter ball sampling probe. The smaller faced subjects pulled the mask close to the face and the ball probe was trapped between the mask and face. This caused considerable discomfort to these subjects and may have compromised the measured performance of the mask. Later tests used the thinner disc probe, which is specified in EN 149 for

inward leakage measurements in filtering face pieces.

Eight subjects found 6 km/hr too fast and requested a slowing down of the treadmill. Six subjects accepted a speed of 5.5 km/hr but two subjects were unable to maintain speeds greater than 4.6 km/hr.

By conforming to the relevant European Standard, the three face masks are given a nominal protection factor of 2000, having demonstrated a percentage inward leakage of less than 0.05%. However, some of our test subjects could not achieve this level of performance with these masks. Test Subject D had facial dimensions which placed her in part of the Los Alamos grid more typical of the male population. She had no difficulty obtaining an acceptable fit with all the items. This reinforces the perception that RPE is primarily designed for male users. In contrast Subject K's face was visibly too small and slim for any of the masks.

From Figure 2 it can be seen that, with certain reservations, composite face size can be a useful predictor of facial fit. Figure 2 also shows that below a certain critical composite face size users are unlikely to achieve a satisfactory fit from full face mask RPE. The value of the critical composite face size depends on the type of RPE chosen.

Subjects F and G achieved very different results despite the similarity in facial dimensions (Figure 1). The two subjects are of different facial types. Subject G has a rounded face with some subcutaneous tissue whereas Subject F has a slim face with very little subcutaneous tissue. The results suggest that subcutaneous tissue is beneficial in forming a face seal.

Clearly Subject F has a facial type which differentiates between her and other test subjects. This was observed to be so, as described above. Whereas the other subjects would be described as having oval faces; Subject F would be described as a triangular face.

Table 2. Face Mask X. A full face mask with integral fan unit normally powered from belt mounted battery, but in this case tested unpowered and without fan fitted. Available in only one size. This mask is popular with larger sized users.

Subject	% inward leakage head still	% inward leakage head side/side	% inward leakage head up/down	% inward leakage talking	% inward leakage head still	% inward leakage average	Pass or fail	Comment
A	0.50	gross leakage, test abandoned					F	Subject instructed in fitting
A	0.05	0.05	0.05	0.07	0.03	0.05	F	
A	<0.001	<0.001	<0.001	0.01	0.02	0.01	P	
B	0.096	0.156	0.118	0.151	0.118	0.128	F	Grossly too large
B	gaps visible at the checks—no test was performed						F	Subject instructed in fitting
D	0.0085	0.0106	0.0188	0.0245	0.0156	0.0154	P	Subject preferred this mask
D	0.0037	0.0139	0.0168	0.0246	0.0186	0.0155	P	this mask
E	<0.001	<0.001	<0.001	0.40	<0.001	0.08	F	Test done with RPE powered
F	0.0061	0.087	1.49	1.14	1.49	0.843	F	Grossly too large
F	gaps visible at the checks—no test was performed						F	Subject instructed in fitting
G	0.48	0.65	0.93	0.43	0.35	0.57	F	Mask loose
G	0.0028	0.0058	0.0112	0.0182	0.0119	0.010	P	Mask uncomfortably tight
G	0.03	0.03	0.02	<0.001	<0.001	0.02	P	Subject instructed in fitting
J	0.02	0.02	0.03	0.04	0.03	0.03	P	Subject instructed in fitting

Table 3. Face Mask Y. A full face mask with integral fan unit normally powered from belt mounted battery, but in this case powered from a variable voltage supply, adjusted to give the MMFR of 140 l/min. Generally a popular mask due to its light weight and comfort.

Subject	% inward leakage head still	% inward leakage head side/side	% inward leakage head up/down	% inward leakage talking	% inward leakage head still	% inward leakage average	Pass or fail	Comment
A	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	P	Subject instructed in fitting
A	<0.001	<0.001	0.01	<0.001	<0.001	<0.001	P	
B	<0.001	<0.001	<0.001	0.0336	0.0017	0.0017	P	Hot at seal but otherwise comfortable
B	<0.001	0.0016	<0.001	0.0144	0.0056	0.0047	P	comfortable
C	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	P	
D	<0.001	<0.001	0.0012	<0.001	<0.001	0.0010	P	
D	0.0025	<0.001	<0.001	0.0021	<0.001	0.0015	P	
E	<0.001	0.01	<0.001	<0.001	<0.001	<0.001	P	
F	<0.001	<0.001	0.066	0.069	0.0016	0.0277	F	Very uncomfortable, slipping despite being uncomfortably tight
F	<0.001	<0.001	0.292	0.011	0.0059	0.0622	F	despite being uncomfortably tight
G	<0.001	<0.001	<0.001	0.0019	<0.001	0.0012	P	
G	0.0035	0.0031	0.0029	0.0040	0.0031	0.0033	P	
H	<0.001	0.03	0.04	0.41	<0.001	0.10	F	Subject instructed in fitting
H	<0.001	<0.001	0.04	0.60	<0.001	0.13	F	Subject instructed in fitting
J	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	P	Subject instructed in fitting
L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	P	Subject instructed in fitting
M	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	P	Subject instructed in fitting
N	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	P	Subject instructed in fitting

Table 4. Face Mask Z. A full face mask normally powered from belt mounted power pack and filter but in this case tested unpowered. Two sizes of mask are available and subjects were allowed a free choice.

Subject	Size	% inward leakage head still	% inward leakage head side/side	% inward leakage head up/down	% inward leakage talking	% inward leakage head still	% inward leakage average	Pass or fail	Comment
B	M/S	0.042	0.069	0.075	0.1299	0.111	0.085	F	Mask extended above hairline
B	M/S	0.178	0.283	0.414	0.813	0.695	0.477	F	
B	M/S	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	P	Subject instructed in fitting
D	M/L	0.0253	0.0317	0.351	0.0344	0.0525	0.0991	F	Subject felt mask was loose
D	"	0.0134	0.0263	0.0343	0.0430	0.0333	0.0301	P	
F	M/L	1.09	1.10	1.10	1.10	1.09	1.1	F	Subject felt mask was too large
F	M/S	0.027	0.029	0.064	0.053	0.203	0.075	F	Changed to M/S
F	M/S	1.59	gross leakage, test abandoned					F	Subject instructed in fitting
G	M/L	<0.001	0.0038	0.0062	0.0082	0.0059	0.0049	P	
G	"	0.0007	0.0013	0.0015	0.0022	0.0026	0.0017	P	
H	M/S	0.09	0.03	0.28	0.02	0.02	0.09	F	Subject instructed in fitting
H	M/S	<0.001	<0.001	0.09	0.01	<0.001	0.02	F	Subject instructed in fitting
J	M/S	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	P	
L	M/S	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	P	

In addition to the above results Subject K tried to fit all the three face mask types including both sizes of face mask Z. In all cases it was evident from visual inspection that a satisfactory fit could not be achieved. Problems ranged from obvious gaps at the sides of the mask to the harness straps having insufficient adjustment. No tests were performed with this Subject.

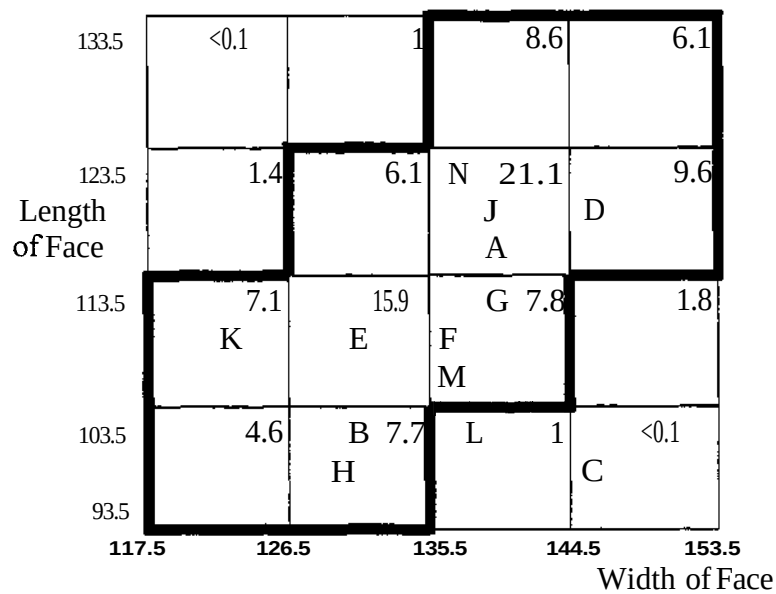


Figure 1. Full face mask test panel. All dimensions in mm. Numbers within cells refer to the percentage of adult population (male and female) with facial dimensions within the size range defined by the cell.

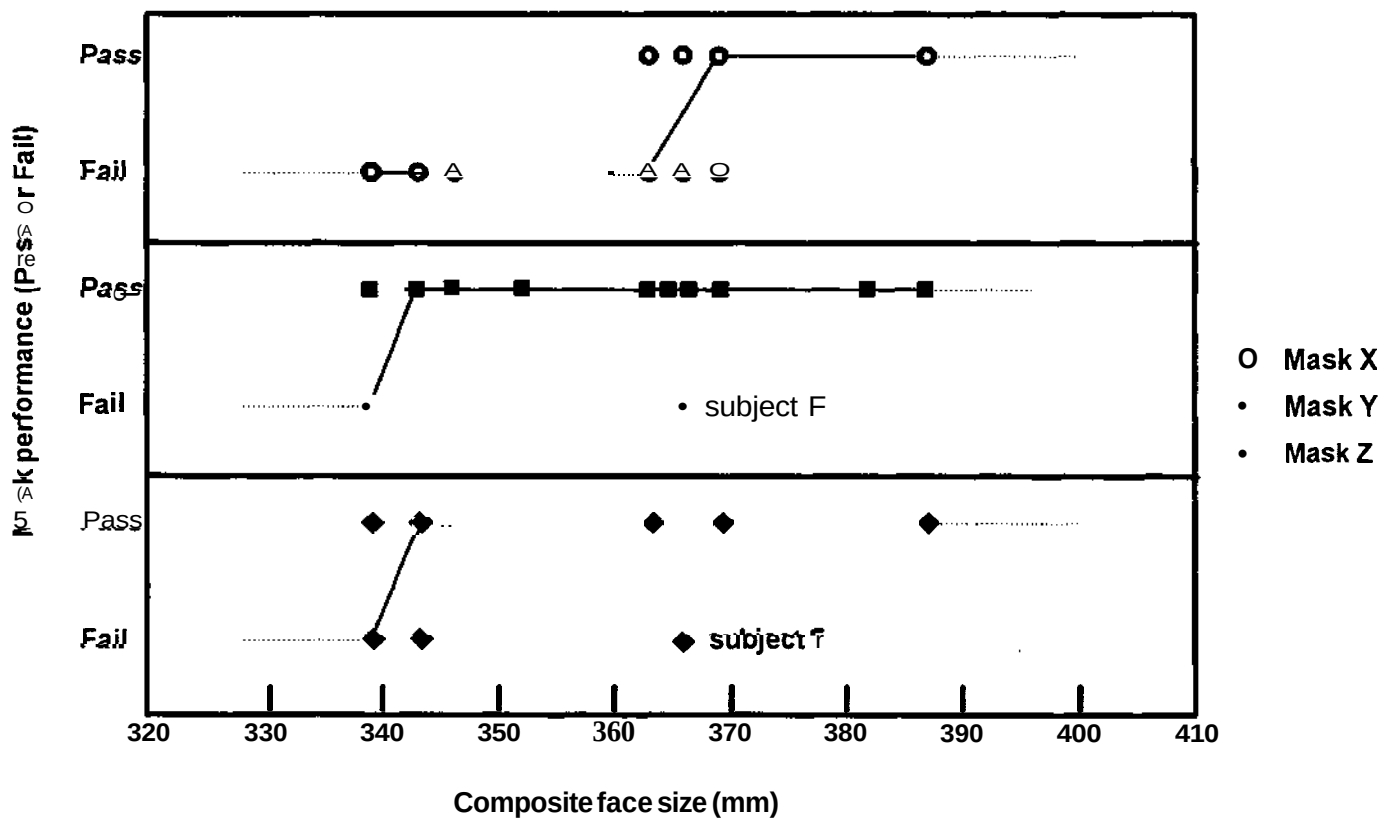


Figure 2. Mask performance against composite face size.

Conclusion

With the three face masks tested, subjects with a composite face size below 340 mm are unlikely to achieve a satisfactory fit whilst face mask X is only suitable for subjects with a composite face size above 370 mm.

The use of composite face size is speculative but with further experience and data, this may become a useful indicator of face mask suitability.

This work suggests that, due to facial type and size, between 10 and 20%, of female users will be

unable to achieve a satisfactory fit from a selection of face masks. Experience of fitting male users suggests that the corresponding figure for them is less than 5%.

This work confirms the value of hoods for wearers who cannot achieve protection from a face mask. A hood or blouse should always be available to female wearers. However, there are limitations on the use of hoods or blouses in areas of restricted access, and where damage to RPE is likely.

References

EN136 (1998) Full face masks for respiratory protective devices. CEN, Brussels.

EN147 (1991) Respiratory protective devices, Power assisted particle filtering devices incorporating full face masks, half masks or quarter masks. CEN, Brussels.

EN146 (1991) Respiratory protective devices: Powered filtering devices incorporating helmets and hoods. CEN, Brussels.

EN149 (1991) Specification for Filtering half masks to protect against particles. CEN, Brussels.

Bailey, A.E., Clayton, M.P., and Vaughan N. P., "Performance of Power Assisted Respirators During Simulated Asbestos Removal," Health and Safety Laboratory, Internal Report IR/L/PE/98/09, 1998.

Hack and McConville, "Development of an Anthropometric Test Panel," *American Industrial Hygiene Association Journal*, Vol. 39 970-975, 1978.